Chapter 4

Description and Comparison of Wood Feature Parameters

4.1 Introduction

In this chapter wood features are described using parameters derived from color and x-ray sensors. These parameters have been measured from wood features and are described in terms of statistical measures, which can be used to characterize their interrelationships and variability. Parameters have been compared statistically to explain their relationships between features. These statistical comparisons were also used as a method to select variables for feature differentiation. The use of these variables in feature differentiation is discussed in Chapter 5. The relationship of parameters between feature types was first examined by comparing them for each species separately. Comparisons of parameters for each feature type were then made between species. Finally, the effect of resolution on the parameters was determined for each feature type.

4.2 Parameter Differences between Features

In this section the relationship of the parameters listed in Table 4.1 for each feature type were compared within each species using analysis of variance techniques. These comparisons were used to show the relationship of parameters to feature types and as a method of selecting classification variables. Parameters that were found to be significantly different between all feature types were suggested to provide the best differentiation between the features and should be included in any classification methods. Parameters that were significantly different between only one or two feature types were considered to not provide good differentiation between features and should be left out of classification methods. Verification of this variable selection method was completed in Chapter 5.

Table 4.1. Definition of parameters used to characterize wood features.

Property	**Notation**	**Parameter Measured From each region (Gray-level based)**	**Image Used to Measure**
Color	R_m	Feature red mean	Color
	G_m	Feature green mean	
	B_m	Feature blue mean	
	R_s	Feature red standard deviation	
	G_s	Feature green standard deviation	
	B_s	Feature blue standard deviation	
	H_m	Feature hue mean	
	S_m	Feature saturation mean	
	I_m	Feature intensity mean	
	H_s	Feature hue standard deviation	
	S_s	Feature saturation standard deviation	
	I_s	Feature intensity standard deviation	
Shape	ASP	Feature aspect	Color
	RND	Feature roundness	
X-ray attenuation	X_m	Feature attenuation mean	X-ray
	X_s	Feature attenuation standard deviation	

Comparisons between feature types for each parameter were made using ANOVA and Tukey's pairwise comparisons where statistical differences were determined using α=0.05. These statistical methods were described in section 3.6.5. Table 4.2. outlines the hypothesis and statistical analysis used in this section. The hypothesis that all feature types had equal parameter values was tested using ANOVA. If this null hypothesis was rejected, then Tukey's multiple comparisons were used to determine which feature types were significantly different from one another. This analysis was conducted for each parameter listed in Table 4.1. The results and discussion of this analysis are presented in the following sections by color parameters, density parameters, and shape parameters for each species.

4.2.1 Red Oak

The complete results of the analysis of variance for red oak features are presented in Tables A6 and A7. These tables present the p-values resulting from Tukey's multiple comparisons between feature types. All values listed as 0.0001 are equal to, or less than this value. The tables are in matrix form, where the features are listed in the top row and left column. The p-values representing the significant differences between the specific feature types are presented in the appropriate row and column. For example, the p-value corresponding to the significant difference between stain/mineral streak and knots for R_m in Table A6 is 0.5252. At the chosen significance level of α=0.05, this p-value indicates that there is no significant difference between the R_m values for stain/mineral and knots for red oak. Only those parameters that have significant differences between feature types for red oak are also presented in Table 4.3. This table is also in matrix form, but lists only those parameters and values found to be significantly different.

For RGB color, it should be noted for red oak that when any one of the R_m, G_m, and B_m parameters were significantly different between two feature types, then all three mean parameters were significantly different for the two features. One example of this similarity can be noted in the comparison of knots and bark pockets. R_m, G_m, and B_m were also found to be significantly different between all feature types except knots and stain/mineral streak as

Table 4.2. Analysis of variance used for each parameter and species.

Hypothesis	H_o: P (knots) = P (Bark pockets) = P (stain/mineral) = P (Clearwood). Where P is a particular parameter. H_a: P (knots) ≠ P (Bark pockets) ≠P (stain/mineral) ≠P (Clearwood). Where P is a particular parameter. When true, Tukey's multiple comparisons were used.			
ANOVA	**Feature Types**			
Measured Parameter	Knots	Bark Pockets	Stain and Mineral Streak	Clearwood

Table 4.3. Parameters that have significant differences between features in red oak.

Feature Type	Knot		Bark Pocket		Stain/Mineral	
	Parameter	p-value	Parameter	p-value	Parameter	p-value
Bark Pocket	R_m	0.0001				
	G_m	0.0001				
	B_m	0.0001				
	H_m	0.0001				
	I_m	0.0001				
	RND	0.0300				
	R_s	0.0059				
	H_s	0.0001				
	S_s	0.0001				
Stain/Mineral	ASP	0.0001	R_m	0.0001		
	RND	0.0001	G_m	0.0001		
	G_s	0.0192	B_m	0.0001		
	B_s	0.0029	H_m	0.0003		
	I_s	0.0236	I_m	0.0001		
	X_s	0.0001	ASP	0.0001		
			RND	0.0001		
			H_s	0.0001		
			S_s	0.0001		
			X_s	0.0027		
Clearwood	R_m	0.0001	R_m	0.0001	R_m	0.0001
	G_m	0.0001	G_m	0.0001	G_m	0.0001
	B_m	0.0001	B_m	0.0001	B_m	0.0001
	I_m	0.0001	H_m	0.0001	I_m	0.0001
	X_m	0.0087	I_m	0.0001	ASP	0.0001
	G_s	0.0120	H_s	0.0001	RND	0.0004
	B_s	0.0001	X_s	0.0008	B_s	0.0003
	I_s	0.0229				
	X_s	0.0001				

noted by the lack of parameters at the intersection of stain/mineral streak and knots in Table 4.3. This result indicates that the mean color parameters were similar for knots and stain in red oak and will not provide good differentiation between these two features.

Note that in Table 4.3, the feature type where the mean RGB color parameters were significant for all comparisons were bark pockets and clearwood. Therefore, mean RGB color parameters would provide good classification variables for bark pockets and clearwood. However, mean color parameters would not provide good classification variables for differentiating knots and stain/mineral streak because no statistical difference was found between these two feature's mean RGB color parameters. Standard deviations for RGB color add little information to improve upon mean RGB parameters. R_s and G_s were not significantly different between more than two feature types as seen in Table 4.3 (R_s: knots and bark; G_s: knots and stain/mineral streak, knots and clearwood); therefore, they will not provide good differentiation between features. For RGB, B_s was found to be the only significantly different standard deviation parameter between three feature types. The lack of significant differences between feature types for RGB color parameters in red oak suggests that measures other than color will be required for the differentiation between knots and stain in this species. The requirement of parameters other than color in wood feature classification has been suggested by Lambinen and Smolander (1996) and Conners et al. (1990) who suggest the use of x-ray imaging for a density parameter.

Unlike the RGB color space, the ANOVA results for the HSI color space (Tables A6 and A7 and Table 4.3) show that all the mean parameters performed differently in the number and types of significant differences between features. For example, in Table 4.3 it can be noted that H_m had three significant differences between feature types, S_m had no significant differences, and I_m had five significant differences. I_m provides approximately the same information to distinguish between feature types as all three RGB mean color parameters, providing further evidence that the mean RGB color parameters are similar to the I_m. Based on the large number of significant differences between the mean HSI color parameters, H_m and I_m are suggested as variables for feature differentiation in red oak.

For HSI, H_m and H_s between bark pockets and others were the features that were significantly different. Therefore, the hue standard deviation does not vary significantly between clearwood, knots, and stain in red oak. Bark pockets were the only feature type found to be significantly different for the saturation standard deviation parameter, S_s. The lack of significant differences found for the HSI color parameters indicates that H_s, S_m, and S_s do not provide any information to distinguish between feature types and will provide poor classification for features in red oak.

X_m and X_s have significant differences between high and low-density feature types (knots and clearwood), but not between features that have similar densities, as noted by the lack of significant differences between knots and bark pockets or stain and clearwood in Table 4.3. Earlier it was noted that RGB color parameters could be used to differentiate bark pockets and clearwood but not knots and stain/mineral streak. While x-ray alone provides little information to distinguish the four feature types, x-ray information used in conjunction with color could improve the ability of differentiating between knots and stain/mineral because there is a significant difference in measured density between these two parameters.

Both ASP and RND have significant differences between all feature types except bark pockets and clearwood indicating that while not sufficient to be used alone in differentiating between all feature types, when combined with other parameters they would provide good classification for knots and stain/mineral streak.

It was noted that the color parameters of both colorspaces provide a measure of difference between some feature types, but not for all feature types. Because no one color parameter will provide differentiation between all feature types, more than one color parameter should be included for the classification of red oak features. Based on the number of significant differences between feature types, the following color parameters are suggested for feature differentiation of features in red oak R_m, G_m, B_m, H_m, I_m, I_s. In addition to color parameters, the following x-ray and shape parameters contribute information and are suggested for feature differentiation: X_m, X_s, and ASP.

4.2.2 Hard Maple

The complete results for the ANOVA for hard maple feature type parameters are presented in Tables A8 and A9. Table 4.4 lists the parameters and p-values that were found to have significant differences between feature types. The tables are in the same format used for red oak and can be interpreted in the same manner. For hard maple R_m, G_m, and B_m show significant differences between all feature types. Because there were significant differences between all feature types for the mean color parameters, R_m, G_m, and B_m should provide good classification variables. Both R_s and G_s have significant differences between the same feature types (knots/stain/mineral streak, knots/clearwood, and clearwood/bark pockets). B_s was only significantly different between knots and clearwood. The lack of significant differences for B_s indicates that it would not be a good parameter for feature differentiation. Since there were a large number of significant differences between all mean and two of the standard deviation parameters, they should provide good classification variables.

For the HSI color space, it was found that H_m was significantly different between all feature types except between knots and bark pockets. The S_m parameter lacked significant differences between knots and bark pockets and between clearwood and stain/mineral streak, indicating that it would not be as good for differentiation between features as the H_m parameter. The I_m parameter provided significant differences between all the feature types as was found for all of the mean RGB parameters. This similarity between I_m and the R_m, G_m, and B_m color parameters was also noticed in red oak. I_m has more significant differences between feature types than any other color parameter in the HSI color space, indicating that for hard maple this parameter should be used for feature differentiation. S_s was significantly different between all feature types except stain and clearwood, indicating that it would be

Table 4.4. Significantly different parameters and their associated p-values for features in hard maple.

Feature Type	Knot		Bark Pocket		Stain/Mineral	
	Parameter	P-value	Parameter	P-value	Parameter	P-value
Bark Pocket	R_m	0.0001				
	G_m	0.0001				
	B_m	0.0017				
	I_m	0.0001				
	RND	0.0213				
	H_s	0.0001				
	S_s	0.0001				
Stain/Mineral	R_m	0.0001	R_m	0.0001		
	G_m	0.0001	G_m	0.0001		
	B_m	0.0001	B_m	0.0001		
	H_m	0.0001	H_m	0.0001		
	S_m	0.0001	I_m	0.0001		
	I_m	0.0001	S_m	0.0001		
	X_m	0.0001	X_m	0.0001		
	ASP	0.0001	ASP	0.0081		
	RND	0.0001	R_s	0.0047		
	R_s	0.0003	H_s	0.0001		
	G_s	0.0085	S_s	0.0001		
	S_s	0.0255	X_s	0.0001		
	I_s	0.0073				
	X_s	0.0001				
Clearwood	R_m	0.0001	R_m	0.0001	R_m	0.0001
	G_m	0.0001	G_m	0.0001	G_m	0.0001
	B_m	0.0001	B_m	0.0001	B_m	0.0001
	H_m	0.0001	H_m	0.0001	H_m	0.0408
	S_m	0.0001	S_m	0.0001	I_m	0.0001
	I_m	0.0001	I_m	0.0001	X_m	0.0001
	X_m	0.0004	X_m	0.0003	ASP	0.0401
	RND	0.0317	R_s	0.0001		
	R_s	0.0001	G_s	0.0036		
	G_s	0.0001	H_s	0.0001		
	B_s	0.0051	S_s	0.0001		
	S_s	0.0001	I_s	0.0001		
	I_s	0.0001	X_s	0.0001		
	X_s	0.0001				

useful in feature differentiation. H_s had three significant differences between feature types indicating that it would make a moderate classification variable.

X_m was significantly different for all feature types except bark pockets and knots as noted in Table 4.4. Since the X_m parameter had significant differences between clearwood and all feature types as well as stain/mineral streak and all feature types it was considered to provide good differentiation between these features. Unlike red oak, X_m should provide good differentiation between clearwood and stain in hard maple indicating a density difference between these two feature types. Density information does not appear to provide any further information for feature differentiation than the RGB mean parameters provide.

ASP and RND for hard maple did not have the same differences between feature types. ASP was significantly different between only stain and other feature types. RND was significantly different between knots and all other feature types as well as stain and clearwood. For stain, both shape measures were significantly different from all other features, indicating that shape parameters were be a good parameter to use in differentiating stain from other features. Since ASP has more significant differences between feature types than RND, it is recommended as the shape parameter for feature differentiation.

For both the RGB and HSI there were many significant differences between mean color parameters indicating that they would be useful for feature differentiation. Color standard deviation parameters did not provide many significant differences between feature types. Based on the number of significant differences in color parameters between feature types the following are suggested for differentiating between features in hard maple: R_m, G_m, B_m, H_m, S_m, I_m, and S_s. In addition to color parameters, the following x-ray and shape parameters contribute information and are suggested for feature differentiation: X_s, X_m and ASP.

4.2.3 White Pine

The complete ANOVA results for white pine for each parameter and feature type are presented as p-values for each parameter and feature comparison in Table A10 and A11. Those parameters that had significant differences between feature types are presented in Table 4.5. These tables are in the same format as those used for red oak and hard maple. For white pine the R_m, G_m, and B_m were found to have significant differences between all feature types, indicating that like hard maple and red oak R_m, G_m, and B_m would provide good classification variables. Overall, the RGB color standard deviation parameters will provide moderate to poor differentiation between feature types. The R_s parameter was found to have four significant differences, G_s have two, and B_s has none. The lack of significant differences between feature types for the B_s parameter has been noted for all species. B_s, which was absent for white pine (Table 4.5), appeared significant once for hard maple (Table 4.4), and was significant for three cases for red oak (Table 4.3). If a standard deviation color parameter is required, R_s should be used because it was found to have the most number of significant differences between feature types as previously discussed.

Color parameters of the HSI color space for white pine features are also presented in Table 4.5. Knots were the only feature type for which the H_m parameter was significantly different from the other features, indicating that H_m would be a good variable for differentiating knots from other features. However, H_m was not significantly different when comparing other feature types as noted in the bark pocket and stain/mineral streak columns in Table 4.5, indicating that this parameter would not be a good overall classification variable. I_m is significantly different between all feature types as noted in all columns in Table 4.5. S_m is significantly different between all feature types except bark pockets and clearwood as noted at the intersection of these two feature types in Table 4.5. Due to the large number of significant differences between features for the I_m and the S_m parameters, both were suggested for feature differentiation. I_s and S_s both have significant differences between all feature types except between knots and bark pockets. S_s has smaller p-values for several comparisons; therefore it is recommend for feature differentiation. The H_s parameter was

Table 4.5. Significantly different parameters and their associated p-values for features in Eastern white pine.

Feature Type	Knot		Bark Pocket		Stain/Mineral	
	Parameter	P-value	Parameter	P-value	Parameter	P-value
Bark Pocket	R_m	0.0001				
	G_m	0.0001				
	B_m	0.0001				
	H_m	0.0056				
	S_m	0.0001				
	I_m	0.0001				
	X_m	0.0001				
	ASP	0.0001				
	RND	0.0001				
	X_s	0.0001				
Stain/Mineral	R_m	0.0001	R_m	0.0001		
	G_m	0.0001	G_m	0.0001		
	B_m	0.0001	B_m	0.0001		
	H_m	0.0005	S_m	0.0375		
	S_m	0.0001	I_m	0.0001		
	I_m	0.0001	RND	0.0389		
	X_m	0.0001	R_s	0.0001		
	ASP	0.0007	G_s	0.0015		
	RND	0.0001	S_s	0.0002		
	S_s	0.0001	I_s	0.0027		
	I_s	0.0001				
	X_s	0.0001				
Clearwood	R_m	0.0001	R_m	0.0001	R_m	0.0001
	G_m	0.0001	G_m	0.0001	G_m	0.0001
	B_m	0.0002	B_m	0.0001	B_m	0.0001
	H_m	0.0007	I_m	0.0001	S_m	0.0001
	S_m	0.0025	X_m	0.0001	I_m	0.0001
	I_m	0.0001	ASP	0.0001	X_m	0.0001
	X_m	0.0351	RND	0.0001	ASP	0.0006
	R_s	0.0001	R_s	0.0001	RND	0.0006
	H_s	0.0001	H_s	0.0001	R_s	0.0001
	S_s	0.0001	S_s	0.0001	G_s	0.0001
	I_s	0.0376	I_s	0.0114	H_s	0.0001
	X_s	0.0001	X_s	0.0001	S_s	0.0001
					I_s	0.0001
					X_s	0.0001

found to have significant differences between feature types in only three cases and was not recommended for differentiation between features.

X_m and X_s were significantly different between all feature types except clearwood and stain, indicating that they would both make good classification variables. Density parameters will provide more benefit to HSI based differentiation methods where there is a lack of mean parameters which differentiate between bark pockets and clearwood, and where there is a lack of standard deviation parameters for knots and bark pockets. As with hard maple, density parameters provide differences between stain/mineral streak and clearwood, indicating a density difference between these two feature types for these species.

Knots, bark pockets, and stain were significantly different for both ASP and RND, indicating that shape measures will provide good classification variables for these feature types. Shape measures should provide differentiation between feature types that density parameters would not.

Color mean parameters provided the largest number of significant differences between feature types and were considered good for feature differentiation. For both color spaces the standard deviation parameters have few significant differences between feature types and would be considered poor to moderate in feature differentiation. Based on the number of significant differences between feature types the following color parameters were suggested for differentiating between features in white pine: R_m, G_m, B_m, S_m, I_m, R_s and S_s. Since density and shape parameters provide differences between feature types that others lack the following are suggested: X_m, ASP, RND, and X_s.

4.2.4 Summary of Parameter Differences between Features

Differences between feature types in red oak, hard maple, and white pine have been determined for each parameter listed in Table 4.1. The R_m, G_m, B_m, and I_m parameters were found to exhibit significant differences between the same feature types for all three species, indicating a similarity between these color parameters. This similarity is not surprising, as intensity is a function of the RGB color space and can be calculated from

$$I = (R + G + B)/3 \qquad \textbf{Equation 4.1}$$

where *I* is intensity, *R* is the red channel, *G* is the green channel, and *B* is the blue channel. For red oak it was determined, based on the number of significant differences between feature types, that color parameters alone will not be able to accurately differentiate all feature types. Mean and standard deviation parameters will be required for both color space classifiers. Hard maple and white pine exhibited similarity in the significant differences between features for color parameters. For both species R_m, G_m, and B_m had significant differences between all feature types. Also, R_s was shown to have the greatest number of significant differences between feature types and was suggested to be good classification variable for features. The parameters selected for differentiating between features are listed in Table 4.6 for the three species. Density parameters were found not to provide significant differences between all feature types for any of the three species; therefore, they would not be suggested for use in single variable feature differentiation. Shape measures were similar to density measured in that they would contribute to feature differentiation in a multi-parameter method, but should not be used alone. The ability of the parameters listed in table 4.6 for feature classification will be tested in Chapter 5.

4.3 Affect of Species on Feature Parameters

In the previous sections the relationship of parameters measured from wood feature types was discussed for each species separately. Comparisons were done for each particular species because analysis of variance for all species showed a significant interaction between species and feature type as seen in Table A12. However, it is important to understand the relationship of feature types between species to determine if the measured parameter relationships are species independent and if classification methods can be developed using these parameters for multi-species. An assumption made by many developers of feature classification algorithms is that features, which are anatomically similar, would also have

Table 4.6. Parameters suggested for use in differentiating between features for the each species.

Species	Suggested Parameters for Feature Differentiation									
Red Oak	R_m	G_m	B_m	H_m	I_m	X_m	ASP	I_S	X_S		
Hard Maple	R_m	G_m	B_m	H_m	S_m	I_m	X_m	ASP	S_S	X_S	
White Pine	R_m	G_m	B_m	S_m	I_m	X_m	ASP	RND	X_S	R_s	S_s

similar color, density, and shape parameters. In this section color, shape, and density parameters were compared for red oak, sugar maple, and white pine features. These features include: intergrown knots, bark pockets, stain\mineral streak, and clearwood. Color, shape, and density are discussed separately in the following sections. The results of the complete analysis of variance are presented as p-values for each parameter and feature type in Tables A13-A16. Those parameters that were significantly different between species are also presented for each feature type in Tables 4.7-4.10. All p-values listed as 0.0001 are values equal to or less than 0.0001.

4.3.1 Color Parameters.

4.3.1.1 RGB Color Parameters

For knots, red oak was significantly different from both white pine and hard maple for R_m, G_s, and B_s as seen in Table 4.7. However, for hard maple and white pine none of the RGB parameters (means and standard deviations) were significantly different as seen by the lack of parameters in at the intersection of values for white pine and hard maple in Table 4.7. This lack of significant differences in values between hard maple and white pine color parameters in the RGB color space can be noted at the intersection of these two species in Tables 4.7, 4.8, and 4.9. The lack of significant differences in color parameters indicates a similarity between hard maple and white pine features that does not exist between either of these species and red oak features. Bark pockets had the greatest similarity of color parameters between the species as seen by the lack of significant differences between species as seen in Table 4.8. For Bark pockets, B_m was the only RGB color parameter that was significantly different between any of the species compared. R_m, G_m, and B_m were significantly different for the three species clearwood as noted in Table 4.10, which was to be expected based on the visual differences between clearwood for these species and on differences recorded in literature (Beckwith, 1979).

Table 4.7. Significant parameter differences between species for knots.

Species	Red Oak		Hard Maple	
	Parameter	p-value	Parameter	p-value
Hard Maple	R_m	0.0077		
	H_m	0.0120		
	S_m	0.0001		
	R_s	0.0043		
	G_s	0.0037		
	B_s	0.0066		
	H_s	0.0001		
	S_s	0.0275		
	I_s	0.0046		
	X_s	0.0074		
White Pine	R_m	0.0001	S_m	0.0004
	G_m	0.0004	X_m	0.0001
	B_m	0.0287	ASP	0.0041
	S_m	0.0008		
	I_m	0.0004		
	X_m	0.0001		
	ASP	0.0451		
	G_s	0.0042		
	B_s	0.0324		
	H_s	0.0014		
	I_s	0.0312		

Table 4.8. Significant parameter differences between species for bark pockets.

Species	Red Oak		Hard Maple	
	Parameter	p-value	Parameter	p-value
Hard Maple	B_m	0.0201		
	H_m	0.0096		
	S_m	0.0020		
	H_s	0.0001		
White Pine	ASP	0.0001	ASP	0.0001
	RND	0.0006	RND	0.0016

Table 4.9. Significant parameter differences between each species for stain and mineral streak.

Species	Red Oak		Hard Maple	
	Parameter	p-value	Parameter	p-value
Hard Maple	R_m	0.0001		
	G_m	0.0001		
	B_m	0.0001		
	I_m	0.0001		
	X_m	0.0001		
	R_s	0.0032		
	G_s	0.0259		
	S_s	0.0001		
	I_s	0.0219		
	X_s	0.0057		
White Pine	R_m	0.0001	X_m	0.0001
	G_m	0.0001	R_s	0.0199
	B_m	0.0014	G_s	0.0155
	I_m	0.0001	S_s	0.0012
	X_m	0.0001		
	X_s	0.0033		

Table 4.10. Significant parameter differences between species for clearwood.

Species	Red Oak		Hard Maple	
	Parameter	p-value	Parameter	p-value
Hard Maple	R_m	0.0001		
	G_m	0.0001		
	B_m	0.0001		
	H_m	0.0001		
	S_m	0.0001		
	I_m	0.0001		
	R_s	0.0001		
	G_s	0.0001		
	B_s	0.0001		
	H_s	0.0003		
	S_s	0.0001		
	I_s	0.0001		
	X_s	0.0005		
White Pine	R_m	0.0001	R_m	0.0002
	G_m	0.0001	G_m	0.0001
	B_m	0.0001	B_m	0.0001
	H_m	0.0001	H_m	0.0006
	I_m	0.0001	S_m	0.0001
	X_m	0.0001	I_m	0.0001
	R_s	0.0001	B_s	0.0122
	G_s	0.0014	H_s	0.0018
	B_s	0.0002	S_s	0.0001
	S_s	0.0001		
	I_s	0.0001		
	X_s	0.0086		

Although the clearwood means were different for all species, R_m, G_m, and B_m values for red oak were much smaller than for hard maple and white pine. The differences between the mean parameter values was calculated for each parameter using

Mean Difference = Color Parameter Species 1 – Color Parameter Species 2 **Equation 4.2**

The results are presented in Table 4.11. The difference between the mean values for red oak and the other two species was approximately twice the mean difference between hard maple and white pine.

All three species had the same trend in I_m between features for the three RGB color parameters. The intensity ranging from lowest to highest is bark pockets, knots, stain/mineral streak, and finally clearwood with the brightest values. This result is not surprising as RGB color parameters are greatly affected by the intensity component and these values directly correspond to the intensity of the feature as discussed in section 4.2.4.

4.3.1.2 HSI Color Parameters

H_m, H_s, I_m, and I_s were not significantly different between white pine and hard maple features, with the exception of clearwood as seen at the intersection of values for these two species in Tables 4.7, 4.8, and 4.9. These similarities provide further evidence that species with lighter colored (intensity) clearwood have other color parameter similarities between features.

All three species have significantly different S_m parameters for clearwood, (Table 4.10), and knots, (Table 4.7). S_m is the only parameter that was significantly different between these two feature types for all three species, indicating that feature types vary more in saturation and that saturation would be a good classification variable in a multi-species classifier. For clearwood H_m, S_m, S_s, and I_m were all significantly different between the three species. Bark pockets were the only feature type that had color parameters that were not

Table 4.11. Difference in clearwood mean color parameters for red oak, hard maple, and white pine.

Differences between Species 1 – Species 2		Difference in color parameter values between Species 1 and Species 2			
Species 1	Species 2	R_m	G_m	B_m	I_m
Hard maple :	White pine	17.8	18.8	22.58	19.71
Red oak :	Hard maple	41.13	39.65	28.61	36.56
Red oak :	White pine	58.93	58.45	51.20	56.27

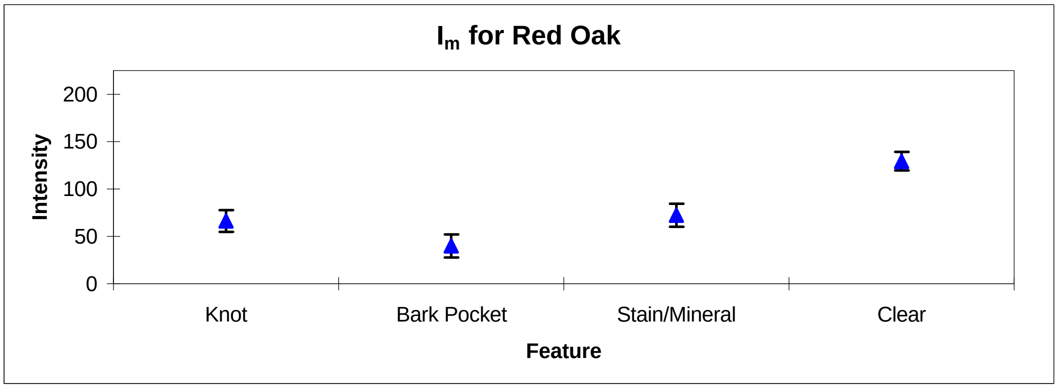
significantly different between the three species. These color parameters were I_m and I_s and their p-values are listed in Table A14.

It should be noted in section 4.2 that for all species in this study the H_s parameter had fewer significantly different feature types than other color parameters. These results indicate that the features examined in this study do not vary greatly in H_s and that, in general, this parameter would not provide useful information in classification methods. The S_s and I_s have more significant differences between feature types and would provide better information for classification methods for these species. For hard maple the H_m and I_m parameters provide the largest number of significant differences between feature types. These results support Sullivan's (1979) observation that the color wood features is two-dimensional. Discriminant classifiers, developed in the next chapter, will be used to verify this observation.

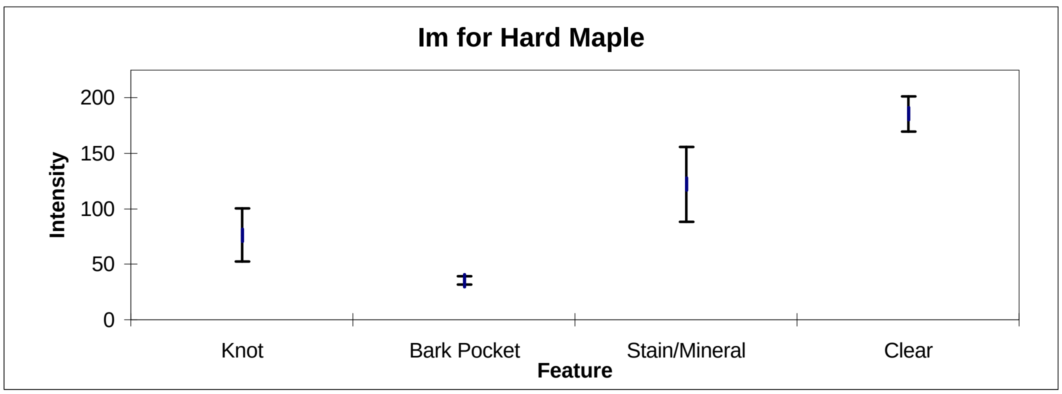
4.3.1.3 Summary of Color Parameters

Bark pockets were the only feature type which had a color parameter that was not significantly different between the three species. The R_m, G_m, I_m, R_s, G_s, B_s, and I_s parameters were not significantly different between species for bark pockets. This result can be explained by the lack of color, or closeness to black that bark represents for all three species investigated. Bark pockets were represented as the darkest feature type in all the species examined.

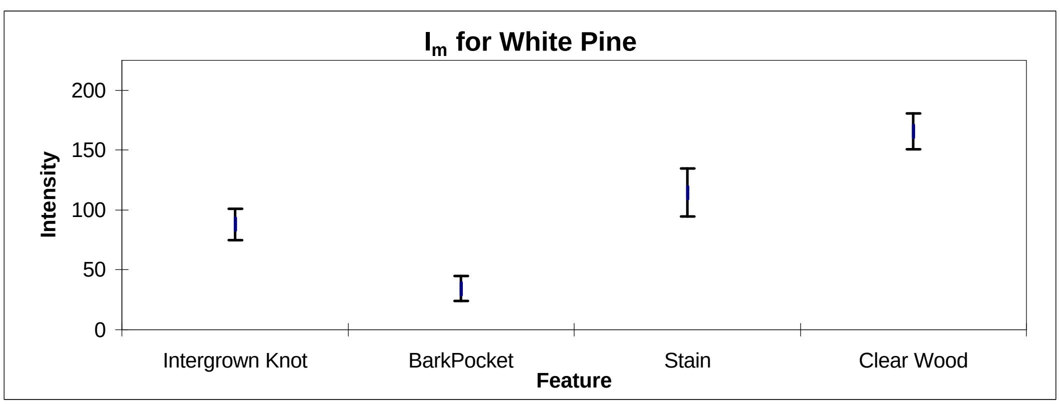
While the magnitude of variation within features differs for each species, it can be noticed that in general, maple and pine feature types contain a greater parameter measure variance as noted in Figure 4.1. This would indicate that it would be more difficult to separate between feature types of these species. This is not the case, as the means of the parameters as seen for I_m in Figure 4.1 have significantly large enough differences that the large variation within the region does not cause them difficulty in separation. Oak has been noted as a difficult species to differentiate between feature types. This difficulty can be explained in part by the similarity in mean values between the features for this species. While



(a)



(b)



(c)

Figure 4.1. The mean and standard deviation for the I_m parameter measured in red oak (a), hard maple (b), and white pine (c).

the variation within feature types may be smaller than other species, since the means are so similar in magnitude the variation between feature types can cause confusion in classification. Also, it has been shown in section 4.2.3 that maple and pine features were more similar to each other in intensity than to any feature in oak.

4. 3.1.4 Feature Color Differences Related to Clearwood

In the previous sections 4.3.1.1 and 4.3.1.2 it was established that differences exist between species for parameters describing a particular feature type and in section 4.2.3 that species similar in clearwood color have similar feature differences. Therefore, the relationship between the color parameters of a particular feature type and those of clearwood for each species was studied. It has been proven that the color parameters of clearwood vary for each species; therefore, it was hypothesized that the color of features within the species was related to its surrounding clearwood color. To test this hypothesis, the mean color differences of features based on the clearwood color parameter of the species were compared. For a particular feature type the percent difference from clearwood was calculated on a subset of data using the equation

$$PD_c = \frac{y_i - y_c}{y_c} x100 \qquad \textbf{Equation 4.3}$$

where PD_c is the percent difference of a feature based on clearwood, $\boldsymbol{y_i}$ is the mean for feature i, and y_c is the mean clearwood value. All mean color parameters were normalized using equation 4.3 for each feature and compared using ANOVA. This analysis was completed for each feature type and the results are presented as p-values for each normalized parameter and species in Tables A17-A19. Several normalized parameters were discovered to not be significantly different for all species indicating that they where related to the clearwood color parameter. These features and parameters are listed in Table 4.12. I_m has the strongest relationship to clearwood for the three features. This observation is based on the number of feature types that its normalized value was not significantly different from. Based on the lack of significant differences between the normalized feature/clearwood, values it can be

Table 4.12. Color parameters for each feature type that have a relationship to clearwood.

Feature	**Parameter**
Knot	I_m, R_m, B_m
Bark Pocket	I_m, R_m
Stain/mineral streak	I_m, S_m, G_m

concluded that clearwood does have a relationship to the feature types that are located within the species.

4.3.2 Density Parameters

The significant differences in the X_m and X_s between species are listed as p-values for each feature type in Tables A13-A16. Those parameters that were significantly different between species are listed in Tables 4.6-4.9. X_m for knots and clearwood were not significantly different for both hardwood species as noted by the absence of the X_m at the intersection of red oak and hard maple in the Tables 4.7 and 4.10. As shown in Table 4.13, white pine clearwood and knots have a significantly lower X_m than the hardwoods as expected. The only feature type for which the X_m and X_s are not significantly different for all species is bark pockets.

To determine if the X_m of a feature type was related to the clearwood X_m of the species the feature X_m value was normalized using equation 4.3 and compared for knots, bark pockets, and stain and mineral streak for each species. X_m is the video gray-scale value (0-255) representing the attenuation interpreted from a x-ray image. The X_m value for knots was found to not be significantly different for both hardwood species as presented in Table A20. The X_m difference between clearwood and knots in white pine is double that of both hardwood species as shown in Table 4.14. This indicates that the ratio of knot to clearwood density is larger for pine than it is for the hardwood species. The density of knot material for spruce has been recorded to be 2.5-3 times that of clearwood (Boutleje, 1965). The difference between the knot and clearwood X_m for each species, based on gray-level differences, is presented in Table 4.13. It can be seen that the average X_m difference between knots and clearwood is much larger for pine than it is for the hardwood species.

4.3.3 Shape Measures

Those features that had significant differences in shape for the species tested are listed in Tables 4.7-4.10. ASP and RND were found not to be significantly different for bark

Figure 4.13. Ratio of knot to clearwood X_m for red oak, hard maple, and white pine.

Species	Clearwood X_m	Knot X_m	Ratio of knot X_m to clearwood X_m
Red Oak	47.9	107.7	2.25
Hard Maple	109.6	130.1	1.19
White Pine	139.1	131.6	1.13

pockets for the hardwood species, but white pine park pockets were significantly different from those in red oak and hard maple as seen in Table 4.8. This result can be explained by the observation that bark pockets found in pine are associated with knots and contain a slight curvature. Roundness in knots is the same for all species. Since shape measures tend to vary for most feature types and shape measures vary little between species, it is suggested that they would provide good classification variables, especially when combined with color or density parameters.

4.3.4 Summary of Parameter Differences between Species

Differences in feature types were shown to exist between species and features with the exception of bark pockets. Bark pockets were the only feature type which had no significant differences between the color parameters for all species. While many features between species have significantly different parameters, hard maple and white pine were shown to have several similar color parameters, indicating that species with lighter intensity are more closely related. The variation between feature type parameters in red oak was shown to be large in comparison to the variation within and can be used to explain difficulty in feature separation. The I_m of features in a particular species was found to relate to the species clearwood I_m. It is possible that this relationship could be used to develop a multi-species classifier where feature values are normalized based on the clearwood intensity value. The density difference between knots and clearwood was found to be greater in pine than in hardwoods, indicating that density will provide a better separation variable for pine than hardwoods.

4.4 Effect of Resolution on Feature Parameters

To determine the effect of spatial resolution on the regional parameters, two different spatial resolutions were compared for each feature and all parameters. Regional measures were collected for each feature using a 30 x 16 pixels per inch resolution and a 15 x 8 pixels per inch resolution. The lower resolution was attained by averaging pixel values. The feature type parameters were then measured using the methods presented in section 3.4. Analysis of variance was used to determine if the two resolutions were significantly different for each measured parameter.

The results of the ANOVA are presented in Table 4.14 as p-values for each feature type and parameter. No significant differences (α=0.05) were found between the resolutions of regional parameters in any of the features; therefore, it is concluded that halving the resolution for these wood features will not affect the parameter relationships. It can be observed from Table 4.14 that the p-values for clearwood are smaller than for other feature types. These small p-values may be a result of a change in color due to averaging of earlywood and latewood bands and possibly due to a reduction in variance through averaging. It must be noted that the regions measured are segmented manually to ensure that all regional measures are related to the actual feature. This measurement technique is a limitation for comparison of resolution. If other segmentation methods were used, then the boarders of regions would possibly include non-feature material and thus change the results. Because resolution was not found to affect parameter relationships, this variable will not be discussed in the modeling of feature parameters.

4.5 Summary

In this chapter color, density, and shape parameters where compared within and between species for intergrown knots, bark pockets, stain and mineral streak, and clearwood. Significant differences between parameters were determined using analysis of variance and Tukey's multiple comparison methods. It was determined that red oak will require more classification variables due to the lack of significant differences between features for most parameters. For hard maple and white pine the RGB parameters should provide good classification between all feature types. For all species, color mean and standard deviation parameters should provide good differentiation between features. Based on the number of significant differences between those parameters listed in Table 4.6 should be used for any feature type differentiation methods. It was determined that the I_m of a feature type was related to the I_m of the clearwood for a particular species. The mean x-ray density parameter

Table 4.14. P-values for significant differences between resolutions.

Parameter	Feature Type			
	Knots	Bark Pockets	Stain/ Mineral	Clearwood
R_m	0.7046	0.4843	0.7419	0.0617
G_m	0.6994	0.4642	0.6902	0.0652
B_m	0.7439	0.5051	0.6941	0.0676
H_m	0.8426	0.7560	0.6285	0.7719
S_m	0.9275	0.9610	0.8264	0.1366
I_m	0.7130	0.4748	0.7109	0.0767
X_m	0.9872	0.8970	0.9999	0.5391
ASP	0.5898	0.6333	0.3755	-
RND	0.1807	0.2981	0.8061	-
R_s	0.0862	0.7647	0.2257	0.0629
G_s	0.0649	0.6380	0.1903	0.0828
B_s	0.0644	0.7279	0.1389	0.0830
H_s	0.0982	0.3392	0.7109	0.0806
S_s	0.3871	0.0530	0.1140	0.0976
I_s	0.0748	0.6662	0.1960	0.0653
X_s	0.9463	0.5407	0.8408	0.1307

X_m will benefit all species feature classification methods, but will have more benefit in the pine and maple classifiers. Shape measures should add to multi-parameter feature differentiation methods, but will not provide good differentiation when used alone. Those parameters selected for feature differentiation by the methods used in this chapter will be used to develop discriminant classifiers in Chapter 5 that will be used to verify the ability of these parameters to classify feature types. The discriminant classifiers will be used to demonstrate that with knowledge of how feature parameters are related to one another and between species, that the best possible classification can be achieved. Since resolution had no effect on the significant differences of any parameter between features it will not be included in further discussion.